FUZZY LOGIC IN MOTOR CONTROL

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ABSTRACT

This paper presents a fuzzy logic solution to a motor controlled positioning system. A modification is made to an existing motor control system which uses Intel's 87C196MC (a 16-bit microcontroller with a special motor control peripheral). In this system, an AC Induction motor acts as a fan. The motor drives air through a vertical tube which moves a styrofoam ball within the tube. Originally the speed of the motor (i.e. airflow) was controlled by the user. This system was modified to allow fuzzy software to control the motor and hence the position of the ball. The paper addresses the design procedure and the implementation of the system.

PROCEDURE

The procedure section of this paper includes a discussion of getting started, defining the system, designing the fuzzy logic control, and implementing the system. This section provides a good basis for designing any fuzzy logic system.

Getting Started

Motor control systems have been around for years and are well tested. Without fuzzy logic, they have worked well. So why use fuzzy logic on an existing working system? How will fuzzy logic improve or help the design? These are questions that are asked at the beginning of any project that could possibly involve a fuzzy logic design. Therefore, it is necessary to recognize the benefits of fuzzy logic in the defined motor control system before starting the design of the system. The operation of the system is easily enhanced using fuzzy logic, therefore, fuzzy logic improves the system performance. After an explanation of the system, the hardware, software and design time considerations are then presented.

Defining the System

The definition of the system involves the addition of hardware and related software for position control. The hardware is complete for a user controlled positioning system. Therefore, the addition of a sensor and its interface to Intel's 87C196MC Demonstration Unit are required to detect position of the ball in the tube. Also the speed of the ball is determined by tracking the distance that the ball travels in some time period. This time period is tracked using the micorcontroller's timer overflow function. A single photo-emitter/detector pair is located at the top of the tube. The photo-emitter transmits an infrared light which reflects off the ball and returns to the photo-detector. The photo-detector drives a current whose magnitude increases with increased infrared light intensity. Therefore, as the ball approaches the center position the current increases. Also due to the low current of the detector, amplification and filtering are required. Figure 1 shows a block diagram for the hardware for the position control system. The

addition of a sensor from the tube provides input for the fuzzy logic system, programmed in Intel's 87C196MC.

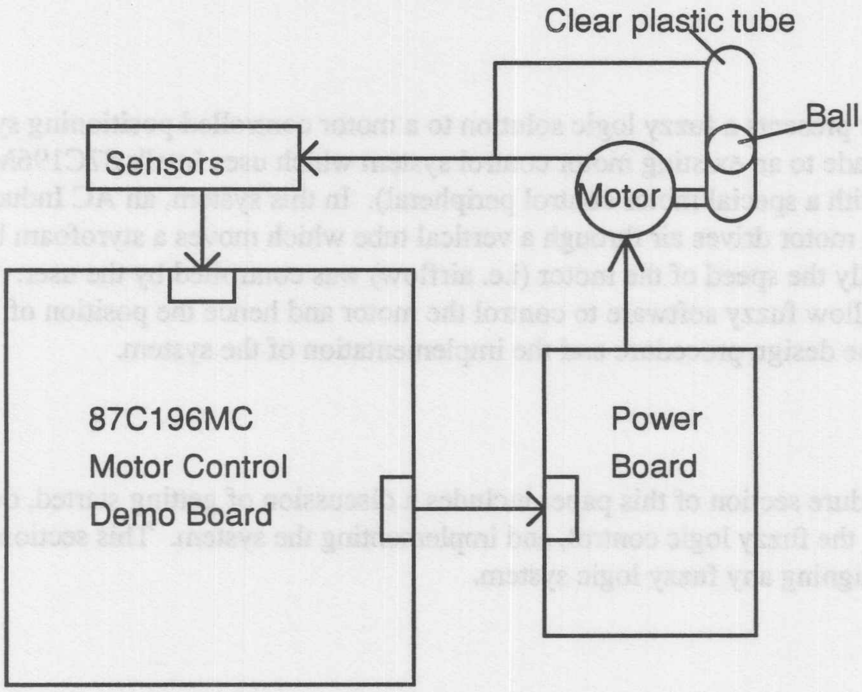

Figure 1. Hardware Block Diagram for Position Control System

The existing flow of the software for the demo unit is shown in Figure 2. The motor is started and the variables and peripherals are initialized. The software then checks to ascertain if any change should be made to the motor speed. This is determined by the increment and decrement buttons on the demonstration unit. If these buttons have been depressed, the 'get new request' routine executes and adjusts a variable according to the button pushed. This variable is passed to the 'update waveform generator' module. The 'update waveform generator' module adjusts the motor controlling PWM to reflect the requested change in motor frequency and volts. These PWM signals drive the Power Board which in turn drives the motor.

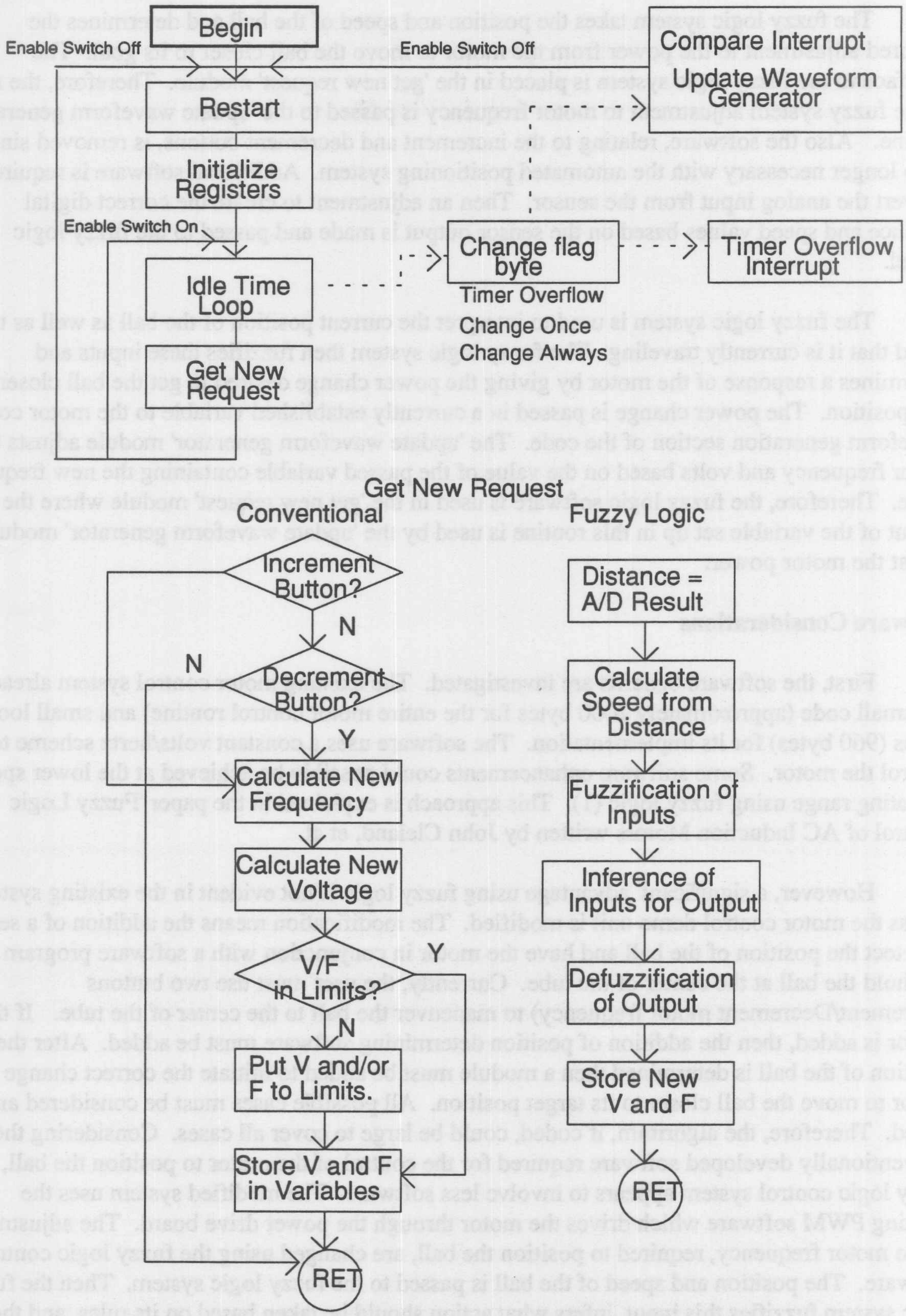

Figure 2. Software Flowchart for Position Control System.

The fuzzy logic system takes the position and speed of the ball and determines the required adjustment to the power from the motor to move the ball closer to its goal. The interface to the fuzzy logic system is placed in the 'get new request' module. Therefore, the result of the fuzzy system adjustment to motor frequency is passed to the 'update waveform generator' routine. Also the software, relating to the increment and decrement buttons, is removed since it is no longer necessary with the automated positioning system. Additional software is required to convert the analog input from the sensor. Then an adjustment to create the correct digital distance and speed values based on the sensor output is made and passed to the fuzzy logic kernel.

The fuzzy logic system is used to interpret the current position of the ball as well as the speed that it is currently traveling. The fuzzy logic system then fuzzifies these inputs and determines a response of the motor by giving the power change desired to get the ball closer to its end position. The power change is passed in a currently established variable to the motor control waveform generation section of the code. The 'update waveform generator' module adjusts the motor frequency and volts based on the value of the passed variable containing the new frequency value. Therefore, the fuzzy logic software is used in the 'get new request' module where the output of the variable set up in this routine is used by the 'update waveform generator' module to adjust the motor power.

Software Considerations

First, the software benefits are investigated. The existing motor control system already has small code (approximately 2000 bytes for the entire motor control routine) and small look-up tables (960 bytes) for its implementation. The software uses a constant volts/hertz scheme to control the motor. Some software enhancements could possibly be achieved at the lower speed operating range using fuzzy logic (1). This approach is explained in the paper 'Fuzzy Logic Control of AC Induction Motors written by John Cleland, et al.

However, a significant advantage using fuzzy logic is not evident in the existing system unless the motor control demo unit is modified. The modification means the addition of a sensor to detect the position of the ball and have the motor in conjunction with a software program place and hold the ball at the center of the tube. Currently, the user must use two buttons (Increment/Decrement motor frequency) to maneuver the ball to the center of the tube. If the sensor is added, then the addition of position determining software must be added. After the position of the ball is determined then a module must be added to initiate the correct change in the motor to move the ball closer to its target position. All possible cases must be considered and coded. Therefore, the algorithm, if coded, could be large to cover all cases. Considering the conventionally developed software required for the control of the motor to position the ball, a fuzzy logic control system appears to involve less software. The modified system uses the existing PWM software which drives the motor through the power drive board. The adjustments to the motor frequency, required to position the ball, are changed using the fuzzy logic control software. The position and speed of the ball is passed to the fuzzy logic system. Then the fuzzy logic system fuzzifies this input, infers what action should be taken based on its rules, and then defuzzifies the output which is the change of power of the motor.

Hardware Considerations

Next the hardware advantages are considered. Regardless of a fuzzy logic or conventional software design, there is no difference in the hardware requirements. Therefore, no hardware advantage in this particular motor control system when using fuzzy logic over conventional design techniques.

Design Time Considerations

Finally, the design and development time, thus time to market, are considered. The fuzzy logic design appears to be a definite advantage in the amount of design time required. Instead of considering all the possible cases that must be included in the algorithm to control the positioning of the ball, the fuzzy logic design easily outlines how a human would respond to positioning the ball. After the designer sat for about a half hour using the increment and decrement buttons to position the ball in the center of the tube, a fuzzy logic system is outlined. The fuzzy logic software is easily developed in an afternoon using Inform's *fuzzy*TECH tool. Some refinements are necessary in implementation, but the basic design is complete. Therefore, based on the software and development time advantages, fuzzy logic is determined to be a good solution to the control problem.

DESIGNING THE SYSTEM

The fuzzy logic system is designed based on the designer's knowledge of how to place the ball into the center of the tube using the increment/decrement buttons. For example, if the ball is far from the target position and it is not moving, the speed of the motor is increased by hitting the increment frequency button numerous times. If the ball starts moving quickly to the target position, there are two possible responses. Neither the increment or the decrement button is pushed until the ball gets closer to the target position. Or the decrement button is pushed to slow the ball's approach to the target position. Finally, if the ball passes the target position, the decrement button is pushed to reduce the motor speed, thus air flow through the tube until the ball floats back to the target position.

This process of how a human reacts to control the positioning of the ball is the basis for the fuzzy logic control system so no complex algorithms are necessary. Therefore, definition of the fuzzy logic control system is straightforward. First, the membership functions for the variables are determined. The variables of the fuzzy logic system are the position of the ball, the speed of the ball, and the motor power increase/decrease percentage. The position of the ball membership function is as shown in Figure 3 where the distance labels (neg_far, zero, etc.) relate to the labels next to the tube in Figure 4. The units on the x-axis represent the size of the tube with 0 inches equal to the middle of the tube. In Figure 4, the ball is in a zero/pos_close position, or just past the target position.

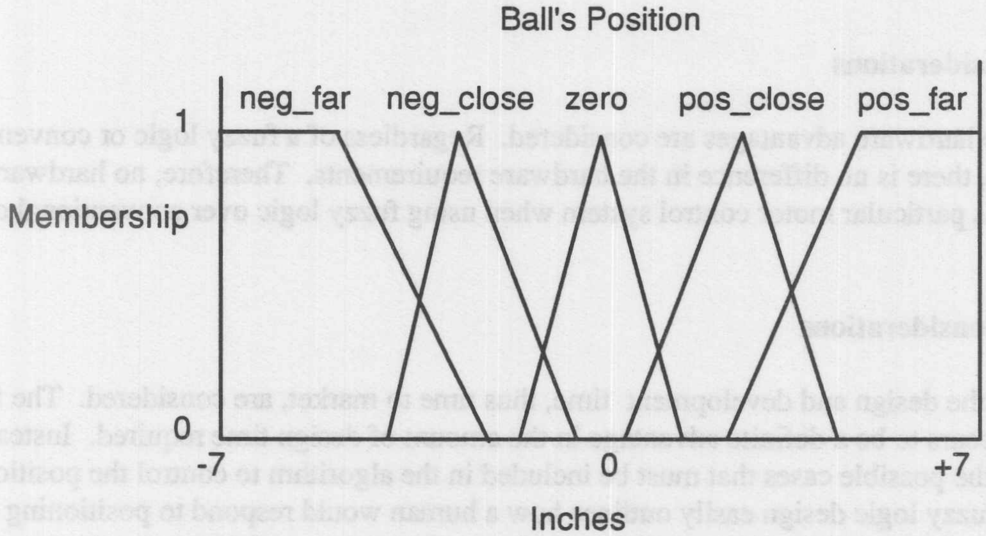

Figure 3. Membership Function for Position of Ball.

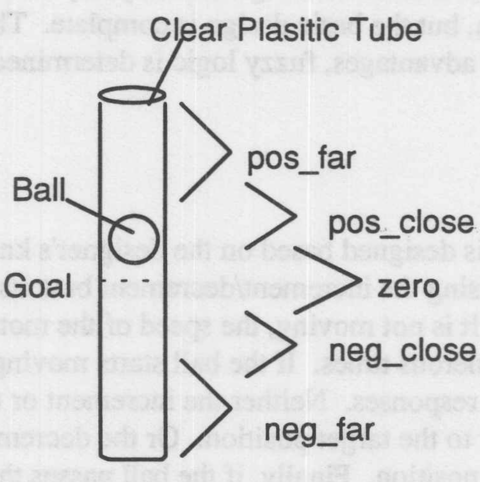

Figure 4. Ball, Tube and Distance Designations from Goal Position.

The speed of the ball membership function is as shown in Figure 5 where the speed direction relates to the arrows next to the tube in Figure 6. The ball can be moving slow or fast in the positive or negative directions. For example, if the ball is moving slowly in the negative direction or down the tube, it is in the neg_slow region.

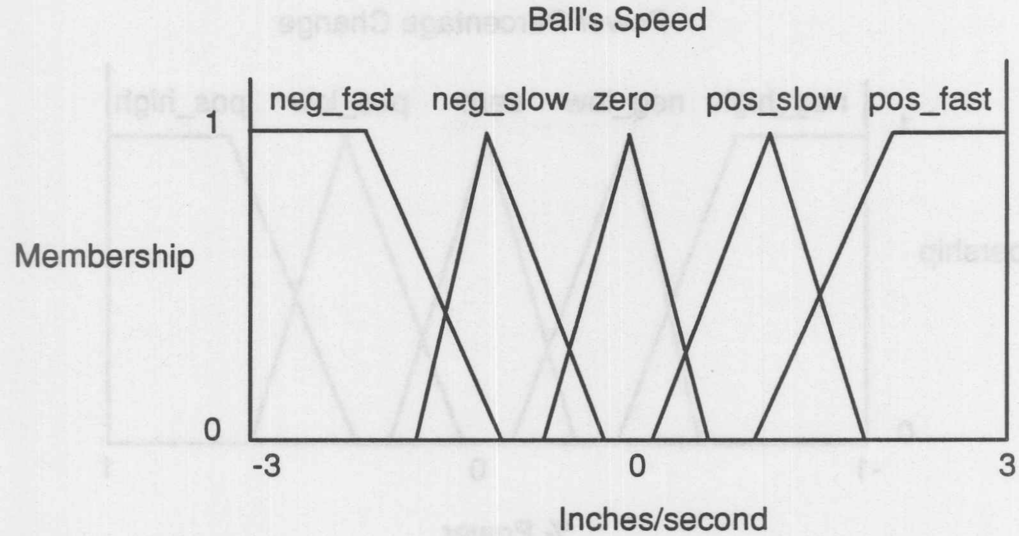

Figure 5. Membership Function for Speed of Ball

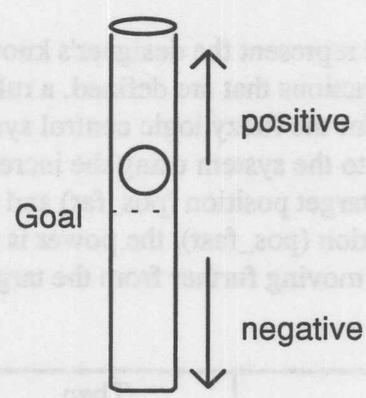

Figure 6. Ball, Tube, and Speed Direction Definition.

The power change membership function is as shown in Figure 7. The positive power change relates to an increase in motor speed. Whereas, the negative power change relates to a decrease in the motor speed. The increase or decrease can be large or small. The percent power change is limited to 1% since the motor cannot experience a large power change at one time.

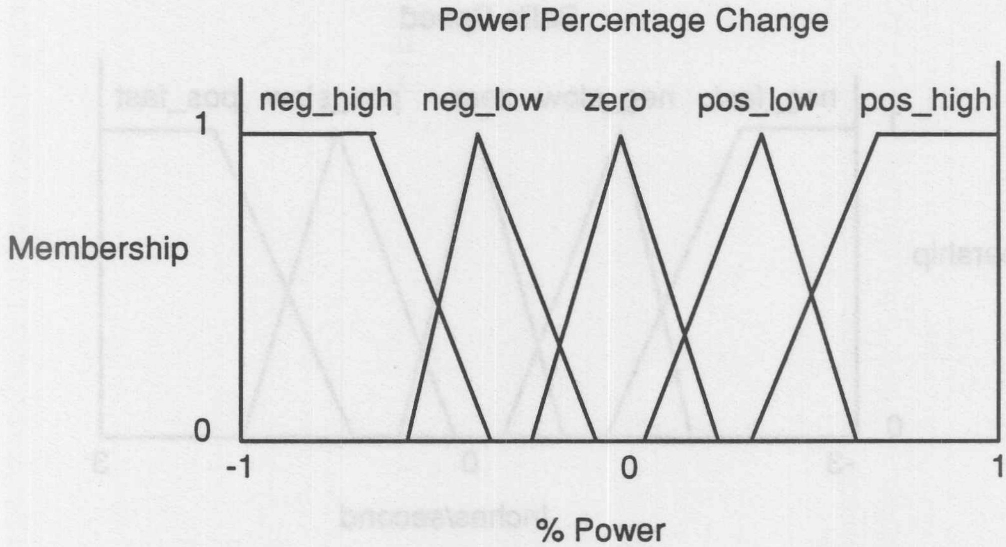

Figure 7. Power Percentage Change Membership Function.

The membership functions represent the designer's knowledge of the system graphically. Now based on the membership functions that are defined, a rule base is developed. Table 1 outlines the initial rule base used for the fuzzy logic control system. These rules are based on how the designer reacts manually to the system using the increment/decrement buttons. For example, if the ball is far past the target position (pos_far) and the speed of the ball is quickly moving away from the target position (pos_fast), the power is reduced by a quite a bit (neg_high). This response slows the ball from moving further from the target and starts moving the ball down toward the target.

If		Then	
Distance	Speed	DoS	Power
neg_far	neg_fast	1.0	pos_high
neg_far	neg_slow	1.0	pos_high
neg_far	zero	1.0	pos_high
neg_far	pos_slow	1.0	pos_high
neg_far	pos_fast	1.0	zero
neg_close	neg_fast	1.0	pos_high
neg_close	neg_slow	1.0	pos_high
neg_close	neg_slow	1.0	pos_high
neg_close	zero	1.0	pos_low
neg_close	pos_slow	1.0	zero
neg_close	pos_fast	1.0	neg_low
neg_close	pos_fast	0.5	zero
zero	neg_fast	1.0	pos_high
zero	neg_slow	1.0	pos_low
zero	zero	1.0	zero
zero	pos_slow	1.0	neg_low

zero	pos_fast	1.0	neg_high
pos_close	neg_fast	0.5	zero
pos_close	neg_fast	0.5	pos_low
pos_close	neg_slow	1.0	zero
pos_close	zero	1.0	neg_low
pos_close	pos_slow	1.0	neg_high
pos_close	pos_fast	1.0	neg_high
pos_far	**neg_fast**	**1.0**	**neg_high**
pos_far	neg_slow	1.0	zero
pos_far	zero	1.0	neg_high
pos_far	pos_slow	1.0	neg_high
pos_far	pos_fast	1.0	neg_high

Table 1. Rules for Fuzzy Logic Position Control System.

Note: These rules may be adjusted upon implementation of system.

IMPLEMENTING THE SYSTEM

The hardware implementation involves the addition of a sensor and an amplifier circuit. Therefore, the amplified sensor output is connected to one of the A/D channels on Intel's 87C196MC.

The software implementation is made easy since Inform's *fuzzy*TECH tool is used to develop the membership functions, the system rule spreadsheet and the fuzzy logic kernel code generation. The kernel is the software called in the 'get new request' module which does the fuzzy logic analysis to position the ball.

Code is required to determine position and speed of the ball in the tube. Some code is required to set-up the analog to digital conversion on the channel connected to the sensor output. Additionally, one of the timers on Intel's 87C196MC is used to determine the speed of the ball. There is an existing timer overflow routine in the software. This routine also has a variable which tracks time and sets a flag when one second has elapsed. Therefore, this timer overflow routine is modified to include converting the sensor output to a digital distance value corresponding to inches. Also the routine is modified to find the distance traveled in one second, thus obtaining the speed in inches per second.

The design time and the performance of the implementation are to be presented at the conference.

SUMMARY

The principles in this paper can be applied to any motor type (AC Induction, DC Brushless, Stepper, etc.). The method for developing fuzzy logic a motor controlled positioning system is illustrated. The problem in this paper was positioning a ball in a tube. However, fuzzy

logic could be useful in other real world positioning problems, such as hard disk drives. This type of solution can also be carried over to other motor control systems such as speed control. As shown in this paper the control problem of positioning is simply solved using a fuzzy logic system. Also no adjustments are necessary if the weight or shape of the ball is changed since the fuzzy logic system is independent of the physical aspects of the ball. Also the time that can be saved in designing with fuzzy logic is invaluable especially in critical time-to-market designs.

REFERENCES AND TRADEMARKS

(1) John Cleland, Wayne Turner, Paul Wang, Todd Epsy, Jeffery Chappell, Ronald Spiegel, and Bimal Bose. 'Fuzzy Logic Control of AC Induction Motors.' IEEE 1992.